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Experimental Investigations on Water Lubricated Hydrodynamic Bearing

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Abstract

To those unfamiliar with the idea of using water as lubricant may not appear promising since it has low viscosity and corrosive nature on ferrous metals.However,it is used in applications such as bearings of the plants(such as nuclear power plant) in which it is used as the process fluid.In the present work, two hydrodynamic bearings are designed using(i)ESDU charts(ii)Reason and Narang technique(iii)Cameron method(iv)Raimondi and Boyd method.All the parameters are calculated using all above approaches and a comparison of clearance,minimum film thickness and power loss etc. has been made from this a decision on clearance is employed for the manufacture of bearings.The necessary metrological measurements were done with help of dial micrometer guage,optical micrometer and surface roughness tester.The experimentations were carried out with proper maintenance of parameters.The materials used are acrylic (Perspex)for bearings and stainless steel for journals. The results are presented in graphical forms for load carrying capacity,side leakage,power loss etc. for different speeds. It is concluded that(i)the design of water lubricated follows the design procedures laid down for oil lubricated bearings.(ii)Materials to be used needs to be properly surface finished,manufactured with adequate tolerances and to be non-corrosive(iii)The load carrying capacity increases for pressure fed condition and if proper clearance is ensured throughout operation,it could still be enhanced(iv)The power loss and temperature are not major issues.(v)Side leakage can be minimized by properly controlling the feed of the lubricant.

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1. Introduction

Considerable attention is being paid to the development of high speed bearings lubricated by low viscous fluid other than oil. To solve this problem, working fluid of a machine could be used as lubricant which could greatly simplify the construction of numerous mechanisms. In specific types of pumps and turbines, the process fluid such as steam or water could be used for water lubrication, which reduces the overall dimensions as there is no need for dividing seals and independent lubrication system with tanks, heat exchangers and so on..Cabrera et al[1] carried out the measurements of fluid film pressure on water lubricated rubber journal bearings and studied the effect of low pressure on the bearings.Hother [2] compared the most important physical properties of water as lubricant with that of light grade turbine oil.The usage of ESDU No. 66023 was recommended to be used for water lubricated applications.Sarvaes [3] studied the effects of force feed lubrication on the performance of full finite journal bearings.Smaardyk [4] evaluated the various types of bearing designs and bearing materials for use in component mechanisms for water cooled nuclear power plants.Sprengel et al [5] embarked on a water bearing testing programme designed to establish comparative wear characteristics and wear predictions for popular non-metallic materials.Yampolski et al[6,7] investigated the scope of water lubricants in steam turbine and also for load carrying capacity of thrust bearings.Simpson et al[8]developed and analysed a nonlinear two degree of freedom model and studied dynamics of water lubricated bearings.Litwin[9] conducted experimental research aiming to verify the influence of roughness pattern on bearing properties.A strong influence of roughness height on movement resistance and working properties of bearings was demonstrated for polymeric materials.Nakano et al[10] developed a proto type of high performance micro turbine system for laboratory evaluation.The rotor system using the water lubricated bearings achieved stable rotating conditions at a rated rotational speed of 51000 rpm.An electrical output of 135 kW with an efficiency of more than 33% was obtained.Hua et al [11] experimentaed with water lubricated bearings for friction coefficient vis-à-vis thickness of rubber of bearings and carried out wear studies. From the literature study it is felt that the applications of water bearings have been experimented by many researchers however there still is possibility to explore newer investigations for other applications.The use of water as a lubricant avoids contamination of the machine with environmentally unacceptable lubricants, in many applications such as in nuclear reactors. The advanced type boiling water reactor (called as ABWR) utilizes internal circulation pumps in place of conventional external pumps located outside a reactor pressure vessel. The internal pump shaft is supported on two journal bearings. These bearings work in warm water under high pressure and low radial force. The pumps in nuclear power plants require reliability as high as that needed for main units such as turbine generators. Thus, properly designed bearings decide the reliability of pumps.Here this application is attempted.

2. Design approaches

Tamboli et al[12] discussed design, development and load carrying capacities of bearings of non-metallic materials. The design approaches used are (1) ESDU chart no. 66023[13] (2) Reason and Narang numerical techniques [14] (3) Cameron method [15](4) Check by Raimondi and Boyd method[16]. These design approaches are well known and used by researchers globally.These design are utilized to decide the clearance and accordingly the bearing and journals are manufactured after optimizing the clearance physically based on comparison of design results. The bearings were inspected precisely after manufacturing. Considering the surface roughness of journal outer diameter and inner surface of the bearing at different locations both axially and radially.

3. Design results

Each methodology has different input and output as shown in Tables 1 to 5.The ESDU[13] uses the set of graphs based on input values.Reason and Narang[14] presented simple amenable technique to calculate bearing parameters using calculator.Cameron[15] has described procedure based on pressure estimation.Raimondi et al[16] utilises various charts keeping bearing characteristics as reference.The following Tables 1,2,3,4 present the calculated results based on different methods as mentioned in section 2.The Table 5 shows the comparison of clearance, minimum film thickness and power loss.

Table1. Results using ESDU [14]

Input Parameters		Design Parameters	
		Diametral clearance, μm	73
Radius of bearing, mm	61.0	Length of axial groove, mm	28.5
Length of bearing, mm	47.5	Width of axial groove, mm	4.0
Performance characteristics			
Eccentricity ratio	0.62	Total flow rate (Q_e), lit/min	0.57
Minimum film thickness, μm	10.22	Velocity induced flow rate (Q_v), m^3 /s (x 10^{-6})	4.65
Rise in temperature, ° c	5^o	Velocity induced flow rate (Q_v), lit/mm	0.27
Power loss, watts	24.73	Pressure induced flow rate (Q_p), m^3/s (x 10^{-6})	4.95

Table 2. Results by Reason and Narang [15]Technique

Input Parameters					
Radius of bearing, mm	61.0		Load, N	1000	
Length of bearing, mm	47.5		Journal speed, rpm	3000	
Performance characteristics for Eccentricity ratio 0.5,0.62					
Surface velocity, m/s	9.58	9.58	Specific pressure, kN/m^2	345.12	345.12
Sommerfeld No.	0.26	0.17	Co-efficient of friction	0.004	0.004
Attitude angle, degrees	57.25	50.73	Non-dim. flow at entrainment	4.438	4.74
Radial clearance, μm	22.36	27.73	Non-dim. Flow through min. film thickness	1.384	1.001
Eccentricity, μm	11.18	17.19	Power loss, Watts	45.21	41.02
Minimum film thickness, μm	11.18	10.54			
Flow ratio	0.68	0.788	Temperature rise,°c	0.012	0.009

Table 3. Results by Cameron [16] method

Input Parameters					
Radius of bearing, mm	61.0		Load, N	1000	
Length of bearing, mm	47.5		Journal speed, rpm	3000	
Performance characteristics for Eccentricity ratio 0.5,0.62					
Somerfield variable, Δ	0.7	1.42	Lubricant flow, lit/min	0.378	0.648
Reciprocal Δ of , $1/\Delta$	1.3	0.69	Axial flow from hole, m^3/s (10^{-6})	0.06	0.22
Attitude angle, degrees	60	51.6	Axial flow from hole, lit/min	0.003	0.013
Radial clearance, μm	27.7	38.3	Co-efficient of friction	0.003	0.003
Eccentricity, μm	13.8	23.7	Power loss, Watts	30.11	21.8
Minimum film thickness, μm	13.8	14.5	Lubricant flow, m^3/s (* 10^{-6})	6.31	10.8

Table 4. Results checked by Raimondi and Boyd [12] method

Input Parameters			
Radius of bearing, mm	61.0	Load, N	1000
Length of bearing, mm	47.5	Journal speed, rpm	3000
Output Parameters			
Pressure, $N/m^2 (x\ 10^5)$	3.45	Torque,N-m	0.11
Sommerfeld no.	0.0910	Power, watts	35.4
Eccentricity ratio	0.6	Max.pressure, $N/m^2 (x\ 10^5)$	0.98
Minimum film thickness,μm	9.95	Ratio of side flow to inflow	0.78
Maximum pressure angle,degrees	40	Angle of max.pressure,degrees	14
Co-efficient of friction	0.0037	Temperature rise,celcius	2.87
Side flow, lit/min	0.63	Eccentricity , μm	24.8

Table 5. Comparison of clearance, h_{min} and power loss values by various design methods

Method			ESDU	Reason and Narang	Test for hyd. lub.	Cameron
L/D = 0.77	ϵ = 0.5	$h_{min,\ \mu m}$	-	11.18	15.8-31 6	13.87
		$c,\ _{\mu m}$	-	23.36	31.6-63.2	27.34
		Watts	-	45.21	-	30.11
	ϵ = 0.62	$h_{min,\ \mu m}$	10.22	10.54	15.8-31.6	14.55
		$c,\ _{\mu m}$	36.5	27.73	41.5-83.1	**38.3**
		Watts	24.73	41.02	-	53.12

The bold clearance value of 38.3 is selected for manufacturing.

4. Experimentation

The bearings and journals are manufactured as per following Table 6 and other parameters considered are as follows.The experiment set up consists of an overhead water tank for gravity fed lubricant to bearing.The pumping of water is done to fill tank from floor level tank.The wattmeter is used in circuit to measure the power consumption.The observations are taken once the flow and operation becomes steadystate.The bearings are loaded by weight pan.The speed is measure by non contact tachometer.Though the design is for 3000 rpm, due to stability limitations the experiments are carried out up to 2000 rpm only.

Table 6. Bearing and journal used for investigations

	Materials	Radius (mm)	Length (mm)
Bearing	Acrylic(Perspex)	30.533	47.5
Journal	AISI304L	30.508	47.5

Lubricant	:	Water
Viscosity at 40 °	:	0.6537×10^{-3} N-S/m^2
Specific heat	:	995 Kg/m^3
Thermal Conductivity	:	4.178 kJ/kg ^oK
Journal Speed Range	:	500-2000 rpm
Range of load	:	50-1000 N
Range of supply pressure	:	$(0-1) \times 10^5$ N/m^2
Range of flow rate	:	0-4.0 lit/min
Dimensions of Supply pipe	:	0.005m diameter
Water inlet Temp.	:	23 ^{o} C
Ambient Temp.	:	24 ^{o} C

5. Results and discussion

The pressure fed condition offers higher load carrying capacity as can be seen from Fig. (1) than the gravity fed condition as it ensures the complete separation of bearing and journal almost at all speeds. The theoretical and experimental values almost match for side leakage for both the load and most speeds which is presented in Fig. (2). The power loss as seen from Fig. (3) is higher in experiments possibly due to the non-concentric condition being not maintained all the time. TheFig. (4) and (5) show the load variations for theoretical and experimental clearance values. The load carrying capacity is higher at high speed such as 2000 rpm and nearly agrees with theoretically values. Experimentally it was observed that the journal and bearing become unstable due to vibrations and observations could not be taken at 3000 rpm. However, at 2000 rpm and below the journal and bearing operate smoothly and hence the results are presented accordingly. TheFigures (1) to (5) are shown in the Appendix.

6. Conclusions

1. The design of water lubricated bearing for hydrodynamic lubrication follows the design procedures laid down for oil lubricated bearing.
2. The Load carrying Capacity increases for pressure fed condition. However, the optimum clearance designed, needs to be maintained while operation along with ensuring the concentricity. Though, the side leakage increases, a trade-off has to be achieved, so as to minimize the side leakage and maximize the load. More ever, the boundary value of pressure is to be maintained for avoiding starvation of the lubricant.
3. The power loss is not a major hurdle as it is very less due to less viscosity fluid being used.
4. The water lubricated bearings in present setup could be experimented up to 2000 rpm only and the load carrying capacity was achieved as 1000 N. If higher speed is desired, then it is felt that the design could be changed accordingly and possibly higher sizes may be sufficient to offer better load carrying capacity.

The load, speed and friction properties under contact of the surfaces are significant as seen by sticking of the surface when load is increased to such high values to cause more power consumption.

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Appendix

The Figures (1) to (5) are the graphs for the various parameters as discussed in the Section 5 above.

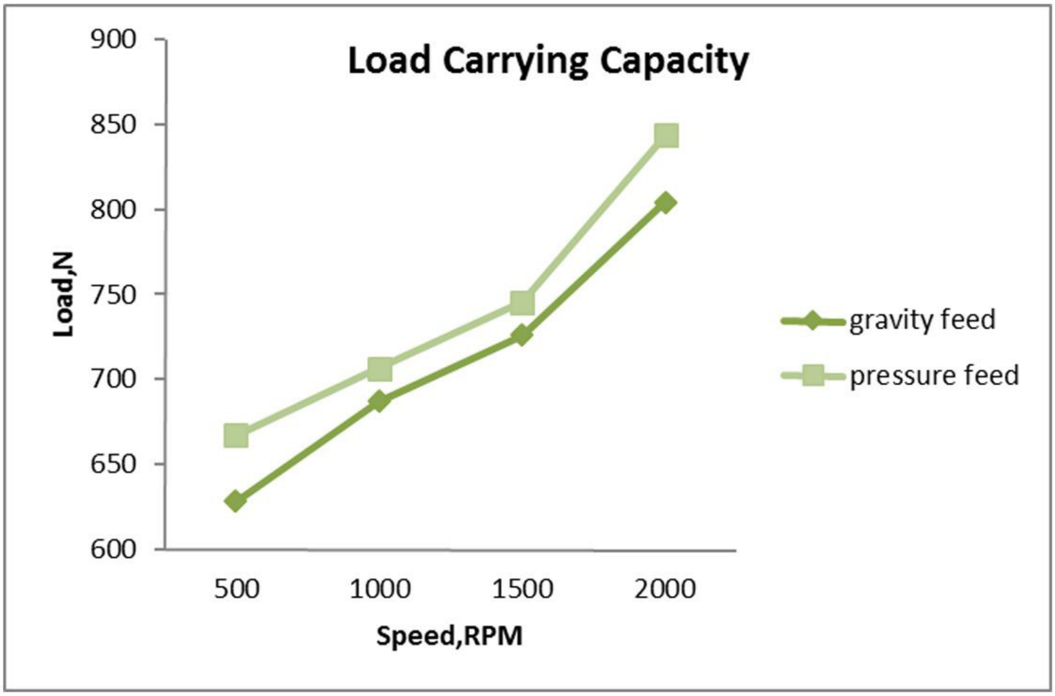

Fig. 1. Load carrying capacity for different feed method of lubricant.

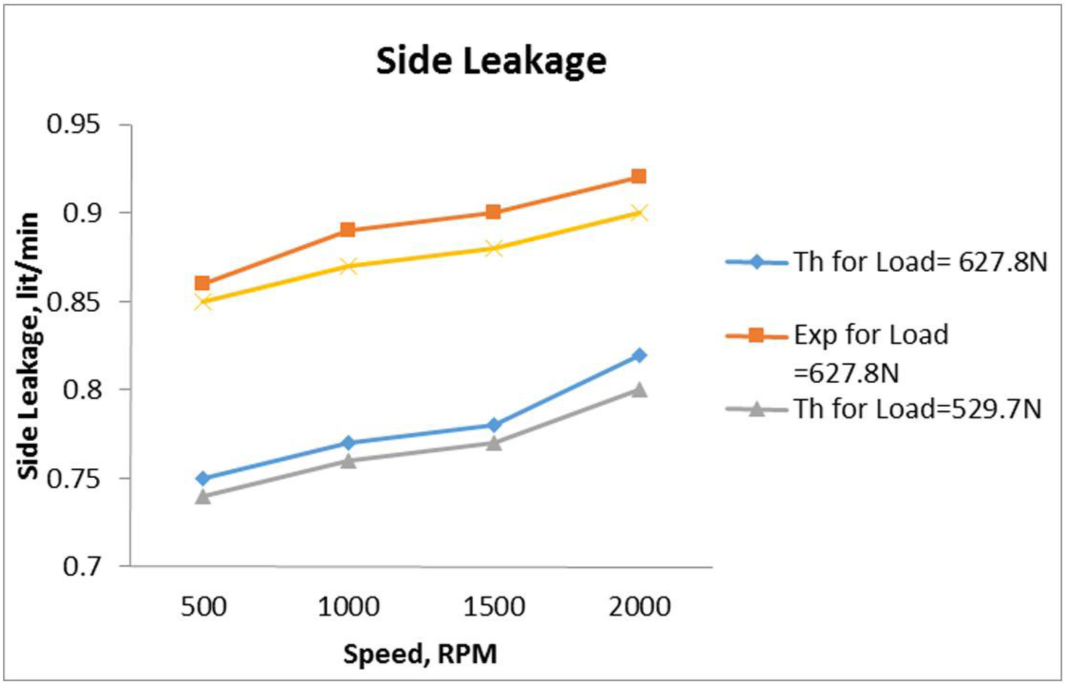

Fig. 2. Side leakage comparison for theoretical and experimental load.

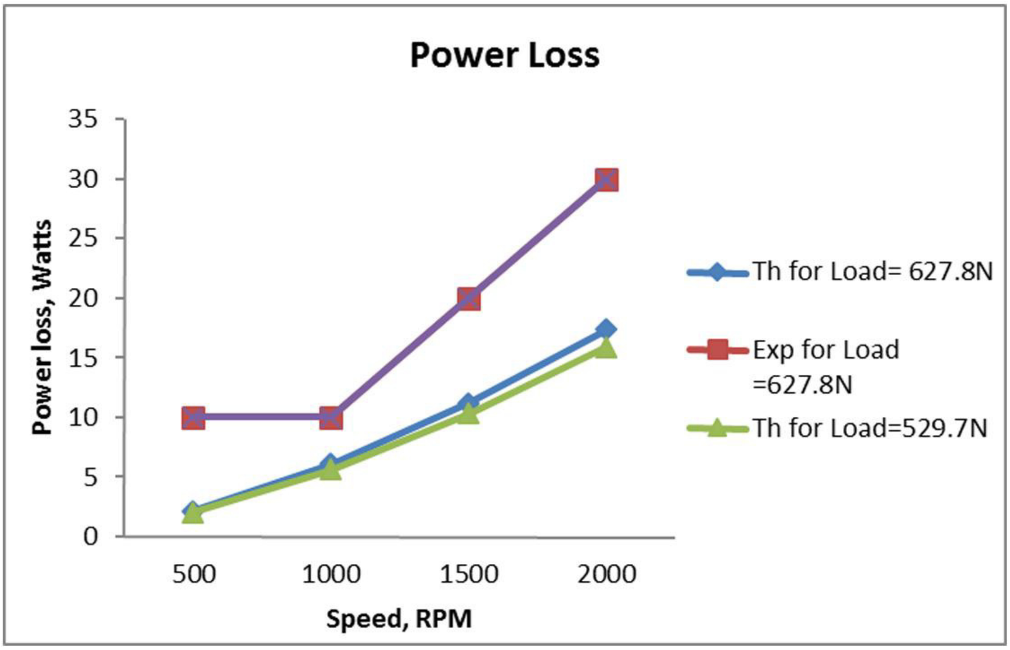

Fig. 3. Power loss for different loads.

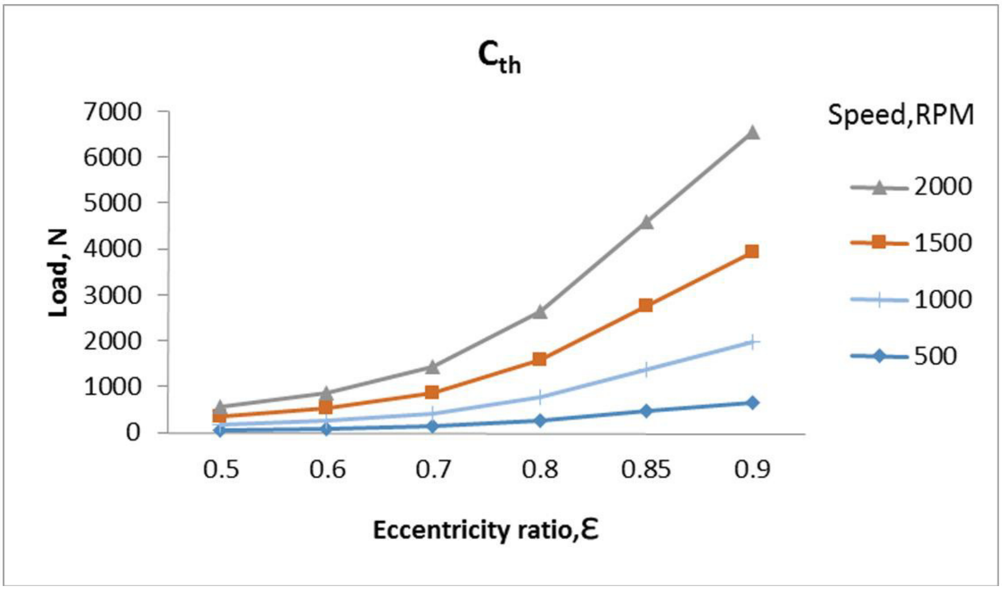

Fig. 4. Load carrying capacity for theoretical clearance values(Cth).

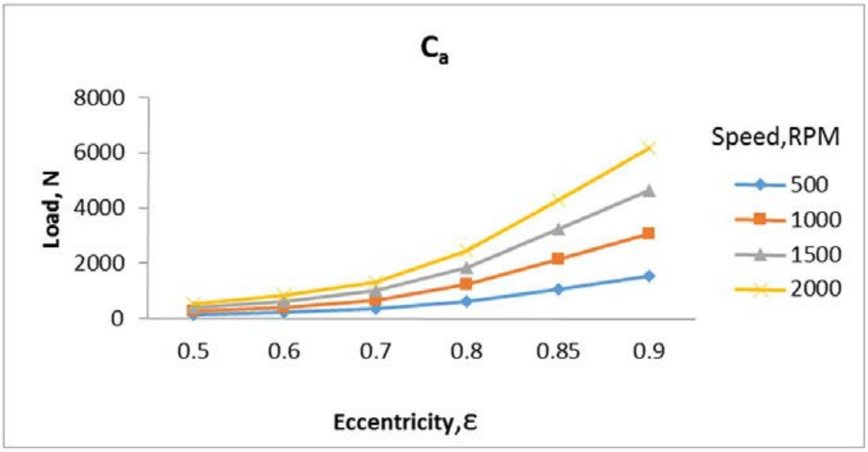

Fig. 5. Load carrying capacity for experimental clearance values(Ca).

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